

Experimental Investigations of EDM Parameters with Graphite Electrode on Copper Tungsten using Taguchi Method

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Abstract: *Electrical discharge machining (EDM) is a machining method primarily used for hard metals which are difficult to machine with traditional techniques. This research is to evaluate the best parameter to spark copper tungsten workpiece with graphite electrode by applying Taguchi method. This experiment can be considered and analyzed the optimal machine parameter as following: Duty factor, On-time, Discharge current, and Open load voltage with consideration of Material Removal Rate (MRR), Electrode Wear Ratio (EWR) and Surface Roughness (SR). As the experiment result, the optimization of all factors for MRR can be seen as following: Duty factor is 20 %, On-time is 17.6 μ s, current is 15 ampere, Open-voltage is 260 volt and the optimization of all factors for EWR can be seen as following: Duty factor at 20 %, ON time at 17.6 μ s, discharge current at 15 A and open load voltage 80V.*

Keywords: *Electrical discharge machining, EDM, Taguchi, optimization*

1. Introduction

Electrical Discharge Machining (EDM) is a machine that is used as non-traditional manufacturing. Furthermore EDM can operate as surface finish in last stage of tool production. Copper tungsten (CuW) is an important tool and die material mainly because of its high electrical conductivity, and wear resistance. Due to its properties, it cannot be processed easily by EDM with normal copper electrode. So EDM process will open up an opportunity for the machining of hard materials. Graphite is produced with a wide range of material characteristics in order to allow matching the electrode material properties to the EDM applications[1]. On the other hand, fabricating for graphite is much easier than a copper. In an EDM operation, it is need to select right parameters for sparking performance. However, the right and desired parameters that base on the experience, instruction manual or a large number of test of experiment that require a lot of time and materials. Therefore, a comprehensive study of the effects of EDM parameters (peak current, machining voltage, pulse duration and interval time) on the machining characteristics such as electrode wear rate, material removal rate, surface roughness, is of great significance and could be of necessity. The Taguchi method, which is a powerful tool for parametric design of performance characteristics, is used to determine the optimal machining parameters for minimum electrode wear ratio, maximum material removal rate and minimum surface roughness in the EDM operations [2-4]. The experimental details when using the Taguchi method are described.

2. Background

The Taguchi method is a technique that provides an efficient methodology for process optimisation. It has been widely used for process optimisation. This is due to the advantages of the design of experiment using Taguchi's technique, which includes simplification of experimental plan and feasibility of study of interaction between different parameters. Shahul Backer et.al investigated the optimization of MRR and EWR on EDM by Using Taguchi's Method and ANOVA. The process parameters such as peak current, pulse on time and pulse off time were optimized with EDM for OHNS EN-31[5]. Rajmohan T. investigated the optimization of Machining Parameters in Electrical Discharge Machining (EDM) of 304 Stainless Steel[6]. The work are carried out as per design of experiment approach using L9 orthogonal array. The results are analyzed using ANOVA and response graphs. From this study, it is found that different combinations of EDM process parameters are required to achieve higher MRR for 304SS. Regardless of category of the performance characteristics, a greater S/N ratio

value corresponds to a better performance. The optimal value of machining parameters is the level with the greatest S/N ratio value. Lesser number of experiments is required in this method. As a consequence, time as well as cost is reduced considerably. Taguchi proposes experimental plan in terms of orthogonal array that gives different combinations of parameters and their levels for each experiment. According to this technique, the entire parameter space is studied with minimal number of necessary experiments only [7, 8]. Based on the average output value of the quality characteristic at each parameter level, main effect analysis is performed. Analysis of variance (ANOVA) is then used to determine which process parameter is statistically significant and the contribution of each process

3. Experimental Procedure

Copper Tungsten (Cu-70% and W-30%) alloy was the target material used in this experiment. Table 1 shows the electrode material related properties. Experiments were performed using a MITSUBISHI: Electrical Discharge Machine, Series EA8. A cylinder of pure graphite (EDM-3) with a diameter of 3 mm was used as an electrode. Kerosene was used as the dielectric fluid in this experiment.

TABLE I: Electrode specification

Average Particle Size (μm)	<5
Flexural Strength (psi)	13,300
Compressive Strength (psi)	18,100
Hardness (shore)	73
Electrical Resistivity ($\mu\text{Ohm-in}$)	615

Source: POCO's EDM-3 [9]

3.1. Design of Experiments

The experimental layout for the machining parameters using the L9 orthogonal array was used in this study. This array consists of four control parameters and three level, as shown in table 3. In the taguchi method, most all of the observed values are calculated based on 'the higher the better' and 'the smaller the better'. Thus in this study, the observed values of MRR, EWR and SR were set to maximum, minimum and minimum respectively. Each experimental trial was performed with three simple replications at each set value. Next, the optimisation of the observed values was determined by comparing the standard analysis and analysis of variance (ANOVA) which was based on the taguchi method.

TABLE II: Design of Experiment of Parameters and Levels

Parameters	Level 1	Level 2	Level 3	Unit
Duty Factor	6	20	50	%
On Time	4.8	17.6	64	μs
Discharge Current	10	15	25	V
Open load voltage	80	150	260	V

TABLE III: Taguchi's L9 Orthogonal Arrays

No.	A	B	C	D
	DF	t_e	I	Vo.
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

4. Results and Discussions

The results and discussions had been focused on the effects of process parameters to the observed values (EWR, MRR and SR) based on the Taguchi methodology.

4.1. Material Removal Rate

As peak current increases, kinetic energy of the spark increases, leading to increase in temperature, material increases which leads to increase in MRR [10]. However, EWR may affect to MRR in the high discharge current. The MRR increases and then decreases after a certain threshold point with increase in 25 A. Further increment in Ton leads to vaporisation of workpiece leading to rise in MRR. The MRR decreases with increase in open load voltage, and then increases after a certain threshold point with increase in 150 to 260 V. Fig. 1(d). As open load voltage increases, the rate of voltage induce increasing of current. The optimal machining condition to obtain maximum MRR was found to be $I = 15$ A, $T_{on} = 17.6$ μ s, $DF=20$ % and voltage = 260 V.

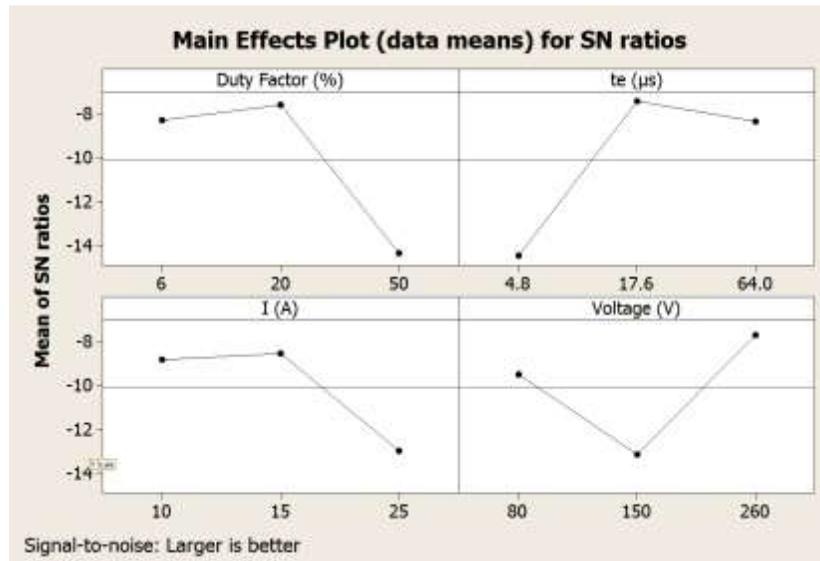


Fig. 1: Main effects for S/N ratio of each factor on MRR

TABLE IV: Response Table for Signal to Noise Ratios (MRR)
(Larger is better)

Level	D.F(%)	te (μ s)	I (A)	(Voltage V)
1	-8.253	-14.452	-8.758	-9.444
2	-7.566	-7.403	-8.481	-13.097
3	-14.354	-8.318	-12.934	-7.632
Delta	6.789	7.049	4.452	5.465
Rank	2	1	4	3

4.2. Electrode Wear Rate

Fig. 2 shows the main effects of EWR of each factor for various level conditions. According to figure 2, the EWR decreases with the two major parameters, D.F and Voltage. And also we notice that minimum machining voltage (negative polarity), maximum peak current, minimum pulse duration and maximum interval time may imply a smaller EWR. Thus, according to I Puertas and C.J.Luis etc.[10], discharge current, discharge voltage are the important machining parameters affecting the electrode wear ratio. The EWR increases and is due to rise in temperature causes electrode wear [11]. The optimal machining condition to obtain minimum EWR is found to be $I = 15$ A, $T_{on} = 17.6$ μ s, $DF=20$ % and open load voltage = 80 V.

TABLE V: Response Table for Signal to Noise Ratios (EWR)
(Smaller is better)

Level	D.F(%)	te (μ s)	I (A)	(Voltage V)
1	-49.62	-50.91	-53.12	-47.12
2	-46.74	-48.84	-49.12	-55.95
3	-58.05	-54.65	-52.16	-51.33
Delta	11.31	5.81	4.00	8.83
Rank	1	3	4	2

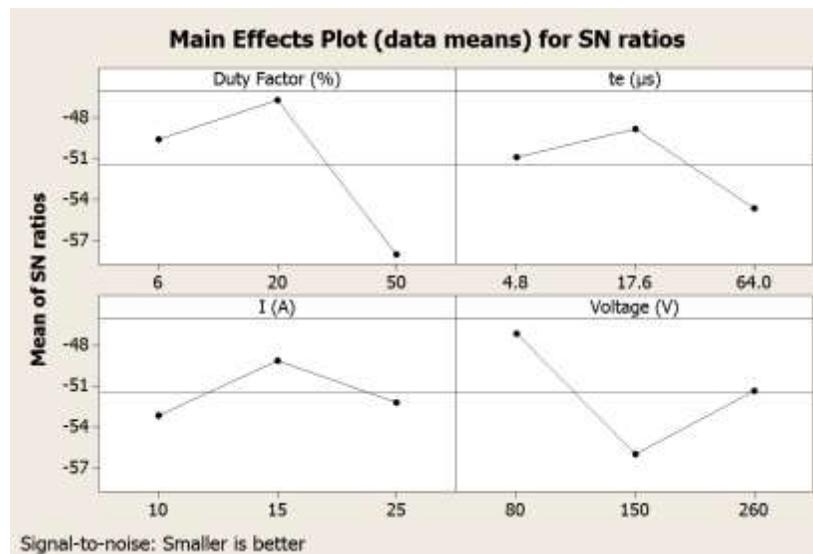


Fig. 2: Main effects for S/N ratio of each factor on EWR

4.3. Surface Roughness

The main effects of surface roughness of each factor for various level conditions are shown in Fig.3. According to this figure the SR increases with voltage and slightly increases with peak current. Larger craters were produced by a larger power supply voltage, possibly producing a larger discharging energy. The influence of peak current on surface roughness is shown in Fig. 4. The surface roughness using 25 A of discharge current is rougher than that using 10 A of discharge current. The variation of crater diameter, depth and volume with respect to peak current is consistent with the general findings in EDM literature that higher currents generate larger crater and therefore produces rough surfaces. The optimal machining condition to obtain minimum surface roughness is found to be $I = 10$ A, $T_{on} = 4.8$ μ s, $DF=6$ % and open load voltage = 150 V.

TABLE VI: Response Table for Signal to Noise Ratios (SR)
(Smaller is better)

Level	D.F(%)	te (μ s)	I (A)	(Voltage V)
1	-18.60	-19.21	-17.85	-20.57
2	-20.24	-20.77	-20.50	-18.55
3	-20.50	-19.35	-20.99	-20.22
Delta	1.89	1.56	3.14	2.02
Rank	3	4	1	2

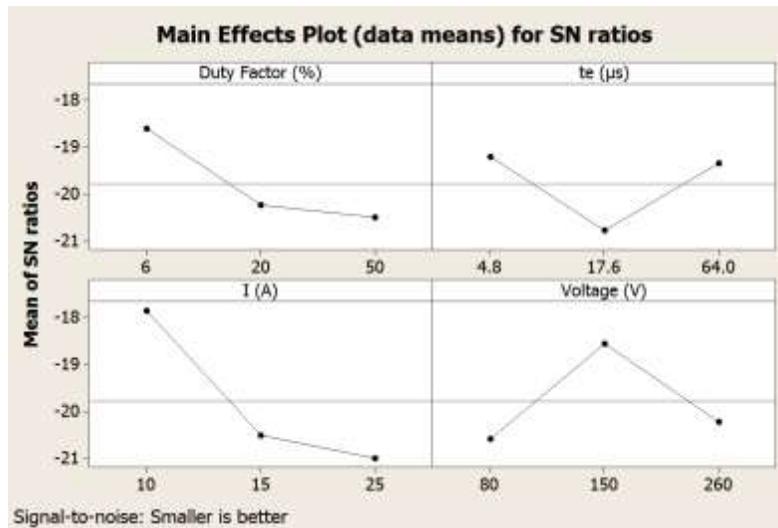


Fig. 3: Main effects for S/N ratio of each factor on surface roughness

a) I = 25A



1 mm

b) I = 10A



1 mm

Fig. 4: Influence of peak current on EDMed surface using a) I = 25A and b) I = 10A

4.4. Confirmation test

The confirmation test for the optimal parameters with its levels were conducted to evaluate quality characteristics for EDM. Table 7 shows the comparison of the experimental results for the optimal conditions with predicted results for optimal (A₂B₂C₂D₃) for MRR. The predicted values were obtained by estimation of MRR = 0.4487 mm³/min while as experimental result gave 0.6551 mm³/min. It can be seen from this table that the difference between experimental result and the estimated result is only 0.206 mm³/min.

The comparisons of the EWR according to optimal test and the predicted combination A₃B₃C₁D₂, and the experiment are given in Table 8. According to these comparisons, the differences were 4.58 %. This verifies that the experimental result is correlated with the estimated result. The response values obtained from the experiments are MRR = 0.65 mm³/min, EWR = 100.47 % .

Surface roughness is 0.62 µm with A₃B₂C₃D₁ which are shown in Table 9. The comparison again shows the agreement between the predicted and the experimental 0.41 µm.

TABLE VII : Results of Confirmation Experiment for MRR

	Estimation	Conditions	Difference
		Experiment	
Level	A ₂ B ₂ C ₂ D ₃	A ₁ B ₃ C ₃ D ₃	
MRR	0.6551	0.4487	0.2064
S/N Ratio	-2.2939	-6.9626	4.6687

TABLE VIII : Results of Confirmation Experiment for EWR

	Estimation	Conditions	Difference
		Experiment	
Level	A ₃ B ₃ C ₁ D ₂	A ₂ B ₂ C ₃ D ₁	
EWR	100.47%	105.13%	-4.58%
S/N Ratio	1.2722	-0.4558	-1.728

TABLE IX : Results of Confirmation Experiment for Ra

	Estimation	Conditions	Difference
		Experiment	
Level	A ₃ B ₂ C ₃ D ₁	A ₁ B ₁ C ₁ D ₁	
Ra	0.62 μm	1.03 μm	-0.41 μm
S/N Ratio	0.4239	-0.2567	0.6806

5. Conclusions

Taguchi method was applied in this study to improve the multi-response characteristics such as MRR (Material Removal Rate), EWR (Electrode Wear Rate) and surface roughness after EDM process. The conclusions of this work are summarized as follows:

- The optimal parameters combination for MRR was determined as A₂B₂C₂D₃ i.e. Duty factor at 20 %, ON time at 17.6μs, discharge current at 15 A and open load voltage 260V.
- The optimal parameters combination for EWR was determined as A₃B₃C₁D₂ i.e. Duty factor at 50 %, ON time at 64 μs, discharge current at 10 A and open load voltage 150V.
- The optimal parameters combination for surface roughness was determined as A₃B₂C₃D₁ i.e. Duty factor at 50 %, ON time at 17.6 μs, discharge current at 25 A and open load voltage 80V.

6. Acknowledgements

The authors gratefully acknowledge the financial support provided by National Research Council of Thailand and the National Research University Project of Thailand Office of Higher Education Commission.

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